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RINGOLD FORMATION OF PLEISTOCENE AGE IN TYPE LOCALITY, THE WHITE BLUFFS, WASHINGTON*

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ABSTRACT. The type section of the Ringold formation in the White Bluffs of the Columbia River consists of a stratigraphic thickness of about 620 feet of horizontally bedded continental sediments lying between river level and the tops of the bluffs, from about 340 to 960 feet in altitude. The beds are of middle to late Pleistocene age.

The uppermost 505 feet of the type section, between 455 and 960 feet in altitude, is composed largely of lacustrine sand and silt. The lower part, extending upward from river level at 340 feet to the base of the lacustrine deposits, at 455 feet, is composed of a weakly indurated conglomerate member that was deposited by river currents. The conglomerate member extends also below river level, down to an altitude of about 290 feet. It is underlain by 100 to 290 feet of lacustrine silt, clay, and sand, and some gravel beds. This lower lacustrine composite, a part of the Ringold, is commonly called the "blue clays" section and lies, in turn, upon the basalt bedrock, whose surface is somewhat irregular but is near sea level in the central part of a broad syncline.

The succession of lithologic types is believed to indicate two stages in the relative uplift of the drainage rim, the Horse Heaven Ridge, in a total amount of about 1,000 feet. The Horse Heaven Ridge is believed to have been a part of the impounding rim. Its main uplift must have been more or less contemporaneous with the deposition of the lower part of the Ringold formation and must have preceded the deposition of the upper part in middle to late Pleistocene time.

INTRODUCTION

Purpose of the Paper

Certain aspects of the history and character of the Ringold formation have been the subject of intermittent study during the last 80 years. However, published reports on the formation differ as to what types of material compose the formation and as to the significance of these types in the geologic history of the region. This paper was prepared in an effort to clarify some of the previous work and to assist in reaching more acceptable concepts regarding the Ringold. It contains information derived from work done during 1950 and 1951 by the Geological Survey for the Hanford Operations Office of the Atomic Energy Commission.

General Composition and Relations of the Ringold Formation

Overlying the basalt bedrock of the Pasco Basin are various unconsolidated sedimentary deposits consisting largely of silt, sand, gravel, clay, and volcanic ash. An important part of that sedimentary cover is the Ringold formation (Merriam and Buwalda, 1917).

The type section of the Ringold formation crops out between altitudes of 340 and 960 feet in the White Bluffs of the Columbia River. Those are the only strata to which the name Ringold formation has been formally applied (Merriam and Buwalda, 1917). In this paper the Ringold formation is extended to include the subsurface continuation of that material—in places completely down to the underlying basalt bedrock which occurs at about sea level beneath the White Bluffs. The Ringold formation crops out also to the north and east of the White Bluffs. There the slightly eroded upper surface of the Ringold underlies, or closely approaches the plateau surface for many miles—

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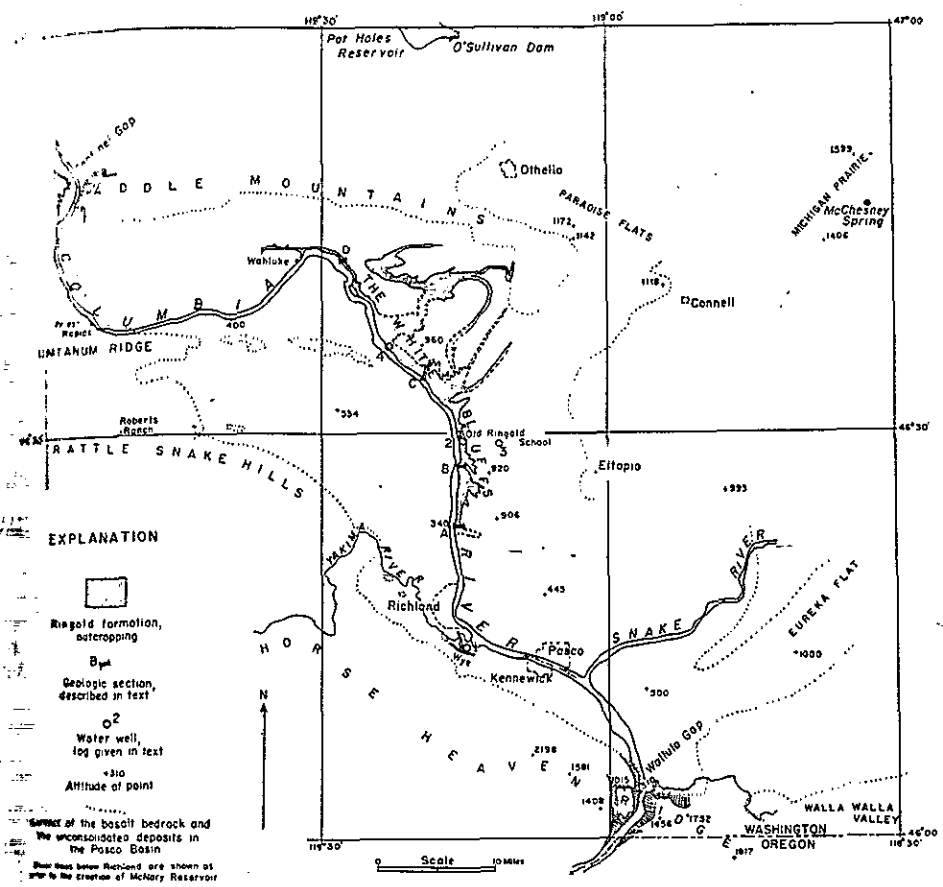
to, and in places beyond, the place where the basalt bedrock emerges at the surface 10 miles north and east of the White Bluffs (fig. 1).



MAP OF THE PASCO BASIN, WASHINGTON SHOWING THE OUTCROP OF THE RINGOLD FORMATION AT AND NEAR THE TYPE LOCALITY

Fig. 1. Map showing outcrop of the Ringold formation in the type area.

In a broad lowland strath west and south of the White Bluffs, the Columbia River has removed a part of the beds of the Ringold to a level below that of the present surface. In this strath, the eroded surface cut across the Ringold formation has been covered, up to a maximum depth of about 150 feet, by water-laid glaciofluviatile and fluviatile deposits. These deposits underlie the terraces of the Hanford, Richland, Pasco, and Kennewick districts. Except for the surface bared by erosion in Recent times, the whole area up to an altitude of 1,150 feet, carries a highly irregular veneer of glaciofluviatile and rafted erratic material.

STRATIGRAPHIC FEATURES OF THE RINGOLD FORMATION

Character and Extent of the Strata in the Type Locality

The Ringold formation in the southern part of its type locality consists of two main lithologic units: the conglomerate member having an exposed thickness of about 115 feet, and an overlying unit of fine-grained sediments about 505 feet in thickness. This upper unit of fine-grained deposits consists mostly of beds of coherent silt, sand, gravel, clay, and volcanic ash. The most prevalent type of material is a weak siltstone containing some interbedded layers of fine sand. Layers of semicompact fine sand make up large sections of the bluffs. The thickness of the individual beds of sand and silt ranges from less than an inch to 10 feet or more. The ash layers range from mere laminar partings to beds 3 or 4 feet thick.

Few of the thin beds extend laterally more than 400 or 500 feet, but some of the thick layers are continuous for several miles. Also, some of the gross layers, in which much the same type of material has a thickness of many tens of feet, can be followed horizontally for miles along the bluffs. That extensive character is especially apparent in the more coherent materials, such as the main conglomerate layer and some of the compact silt layers. The main conglomerate layer extends both above and below river level, in the general altitude range of 290 to 455 feet, along the southern part of the White Bluffs, but only the upper 115 feet has heretofore been included in the Ringold formation.

As previously noted by Culver (1937, p. 60) and other workers, the uppermost part of the Ringold formation in the White Bluffs is heavily calcified and silicified to a depth of at least 15 feet. This calcified and silicified caprock is commonly called "caliche," though it lacks the nitrate constituents inherent in true caliche. The indurated caliche underlies the 900- to 1,000-foot plateau that extends east and north from the White Bluffs. The caliche forms a resistant caprock to the section exposed in the White Bluffs, but is absent beneath the surfaces cut in the Ringold by glacial melt water during the Wisconsin glacial stage and by post-glacial erosion.

The Ringold formation contains the fossilized bones of many types of vertebrate animals and some scattered carbonized wood and other plant matter. On the basis of the vertebrate fossils, the age of the beds was determined as Pleistocene by Merriam and Buwalda (1917), and the fossils were further determined as of middle to late Pleistocene age by Jean Hough (Strand and Hough, 1952).

Material similar in lithology to the type Ringold formation extends downward to the basalt bedrock—or to a thin transitional deposit that may be a pre-Ringold weathering, or soil, zone at the top of the basalt. Although no paleontologic evidence has been secured to prove the material below river level as an extension of the type Ringold formation, the lithologic similarity and the stratigraphic continuity of those "below-river-level beds" are believed to establish them definitely as a downward extension of the Ringold formation of the type locality.

Stratigraphic Sections of the Ringold Formation in the White Bluffs

Geologic sections that were examined vertically across the strata exposed in the White Bluffs are described below; each section was measured with a spirit level from a datum established by controlled barometric leveling from bench marks. The geologic sections are numbered A, B, C, and D, as on the map, figure 1.

A. Geologic section westward down the bluffs at a point north of Pasco Farms pumping plant and near the west quarter-corner of sec. 1, T. 10 N., R. 28 E. Section downward from leveled mark at top of escarpment at altitude of 882 feet:

	Altitude (feet)
Covered, soil, and reworked rubble as of 694-629-ft zone	882-714
Covered, tan, silty soil	714-694
Covered, reworked rubble eroded from caliche caprock	694-629
Siltstone, sandy and clayey, tan, massive at base and progressively more finely laminated toward top; thin sandy layers contain a few pebbles and cobbles	629-623
Sand, medium and fine grained, progressively more silty upward and indurated to sandstone at top, some reworked fragments of siltstone of the Ringold included	623-615
Clay, sandy and silty, massive, buff-green at base and darkening to brown-green at top	615-601
Sandstone, indurated, fine and medium grained, composed mainly of sand-size ash, has minute cross bedding laminae, a strong bed extending horizontally for several miles	601-595
Volcanic ash, clayey, white, dense, massive with conchoidal fracture near base and finely laminated; top part is made up of loose silt-sized shards	595-589
Clay, silty, brown, massive at base but more laminar toward top, in places contains a 2-ft bed of fine sand that is weakly coherent in the center	589-580
Claystone, dark brown, crumbly, massive	580-575
Silt, clayey, grading to silty clay in upper part, tan, massive, top foot is calcareous clay	575-557
Sandstone, similar to 550-542 zone but of whitish-tan color	557-550
Sandstone, fine-grained, weakly indurated, silty and clayey, massive but with highly uniform size of sand grains; top 5 inches is hard cemented layer	550-542
Clay and silt, brown, compact, semiplastic when wet; sandy beds irregularly distributed	542-504
Siltstone, massive, gray, partly indurated	504-494
Silstone, clayey, massive, yellowish at base and gray above; upper 6 ft has many round concretions up to 10-inch diameter; has calcified zone of 1 to 2 ft thickness at top	494-480
Sand, fine, and sitly sand, fine, laminar bedding; material is gray and contains much mica on bedding planes	480-475
Covered, soft material	475-470
Conglomerate, cobble and pebble gravel with some boulders up to 8-inch diameter and with a matrix of quartzose and arkosic medium-grained, well-sorted sand that comprises about one-half of the material; the exotic pebbles and cobbles are mostly quartzite and dense porphyry, granitic types are rare; exotic rock types and Columbia River basalt about equal; locally, beds up to 6 inches thick are entirely sand, firmly cemented, and stand out as resistant ledges; in 435-415-foot zone many pieces of water-rounded and reworked siltstone of the Ringold are present; pebbles are mostly fresh and clean but those of Columbia River basalt have 1/16-inch whitish weathering rind and some granitic pebbles are crumbly	470-415
Covered	415-349

B. Westward down the bluffs at power line in sec. 12, T. 11 N., R. 28 E., from altitude of 716 feet:

	Altitude (feet)
Covered, soil	716-650
Clay, progressively more silty upward, massive, vertical dikes of sand from the sand layer below	650-639
Sand, fine-grained, angular, micaceous, with horizontal and crossbedding, loosely compacted in upper 5 ft; silty sand layers intermixed, basal 3 inches is strongly cemented and contains scattered pebbles	639-606
Clay, silty, tan	606-604
Clay, greenish	604-600
Clay, tan	600-597
Clay, plastic, greenish-brown	597-591
Clay, plastic, tan, iron-streaked	591-588
Silt, massive, tan and yellow banded, becomes more clayey upward	588-567
Sand, silty, fine to medium grained, compact, angular, crossbedded, with concretionary lumps and nodules; upper 10 ft is finer grained, silty, and contains no concretions	567-532
Clay, plastic, jointed, greenish-brown	532-529
Sand, silty, angular, medium-grained, becoming more silty upward; a 6-inch bed at base is iron-stained flaggy sandstone containing a few pebbles and cobbles up to 4 inches in diameter	529-503
Sand, silty, generally loose but compact in places, crossbedded, micaceous, becoming more silty and clayey toward top; light gray	503-490
Clay, silty, tan in lower part grading upward into light brown, plastic, relatively pure clay	490-478
Clay, silty, massive, grading upward into clayey white volcanic ash	478-475
Clay, massive, light tan but brown in lower 4 ft	475-467
Clay, plastic, dark brown	467-465
Clay, silty, massive, tan	465-462
Sand, clayey, well compacted, rudely stratified and progressively more massive toward top; tan colored; has thin laminae of gray clay and iron-stained bedding planes	462-454
Sand, medium-grained, angular, micaceous, tan colored; loose in lower part but compact and well bedded in upper part; upper surface shows channel erosion with 2 to 4 ft of relief	454-433
Conglomerate, well-rounded pebbles and cobbles with a few boulders in a matrix of medium-grained, indurated, clean, angular, quartz sand; rude foreset bedding stratifications are present and the upper 20 ft contains several 6-inch beds of sand that are cemented to hard resistant rock; pebbles and cobbles consist of 70 percent exotic rock types (45 percent quartzite and 25 percent porphyries and granitics) and 30 percent basalt; the basalt particles have a whitish weathering rind up to 1/8 inch thick	433-346

C. Southward down bluffs to junction of a farm lane with "River Road" in NE¼SE¼ sec. 33, T. 13 N., R. 28 E., from altitude of 908 feet:

	Altitude (feet)
Covered; soil with erratic cobbles and pebbles near base	908-891
Caliche; a calcareous and siliceous lumpy horizontal "caprock"	891-884
Claystone, silty, and clayey siltstone; well laminated in 1/4-inch to 2-inch bands, lower half silty and upper half silty claystone; whitish buff color	884-802
Siltstone, sandy, clayey, irregular in firmness and size of grains; a central reddish concretionary zone is a prominent cliff former	802-786
Claystone, silty, and clayey siltstone, massive, bluish color	786-761
Sand, fine and medium grained, loose, micaceous in the partings, intricately crossbedded, top is an erosional surface with 5 ft of relief in 50 ft distance but of a general even altitude	761-741
Siltstone, sandy with many sand partings (cemented) and many concretions; upper and weaker part of a strong siltstone cliff-forming zone whose material is a gradational phase between claystone below and sand above	741-702

Siltstone, bedded in laminae 1/2 inch to 2 inches thick, some clay silt and very fine sand laminae, lowest 4 ft and top part are gradational to material below and above	702-673
Claystone, laminated very finely at base and progressively coarser above; smooth, novaculitelike material, whitish buff	673-662
Sand, fine-grained, firm, gray and brown	662-649
Silt and sand interlaminated	649-640
Sand, silty, medium to fine-grained, rather loose except for 2- to 6-inch cemented layer at base; finely crossbedded, gray sand with silty laminae	640-616
Siltstone, laminated in bands, each 1/4- to 1/8-inch thick, whitish buff, similar to underlying claystone	616-602
Claystone, banded in yellow and gray-buff laminae 1/4 to 1/2 inch thick; a strong cliff former and distinct marker zone of considerable lateral extent	602-589
Siltstone, clayey, massive, buff toward base and bluish above, has much nodular concretionary matter	589-582
Sand, medium-grained, with silt interlayered in 3- to 12-inch beds at base but progressively more silty toward top; the sand is finely crossbedded in waterlaid (lake-current) type of deposition	582-570
Sand, medium-grained, loose, clean, crossbedded, micaceous	570-543
Claystone, silty, dark, damp, with much nodular concretionary matter	543-526
Clay, silty, and clayey silt, blocky and massive, whitish buff in lower 30 ft and dark brown-green toward top; fossil bones of peccary *Platagonus* at 525-ft level	526-471
Clay, silty, dark green and brown but whiter toward top; contains much secondary gypsum, iron oxide, amber and carbonized wood	471-461
Sand, medium- to fine-grained, whitish, with secondary gypsum crystals common at the base	461-458
Silt, partly indurated, whitish	458-454
Silt, sandy toward base but more clayey and more compact upward; top 10 ft is a green-drab claystone that is hard and "flinty"	454-428
Sand, medium and fine-grained, fairly loose, brown; base not exposed	428-426
Covered	426-410

D. Westward down the bluffs to river's edge just east of the north quarter-corner of sec. 17, T. 14 N., R. 27 E., from an altitude of 584 feet. The top is an eroded surface overlain by glaciofluviatile deposits.

	Altitude (feet)
Siltstone, massive, blocky with interlayers of sandy silt laminae and sand	584-547
Clay, silty, like 533-518-ft zone but with more siliceous nodules	547-535
Volcanic ash, white, glass shards of silt and sand (minor) size	535-533
Clay, cream colored; contains silica nodules up to 4 inches in diameter	533-518
Siltstone, clayey, cream to white color, iron-stained	518-488
Claystone, silty, brownish-buff color	488-470
Siltstone, slightly micaceous, massive, gray to white; erodes to a coarse badland-type topography	470-430
Clay, massive, jointed in blocks; contains white calcareous nodules; gray to brown in color	430-418
Clay, silty; in lowest 6 ft has pods and streaks of calcareous deposit but grades upward into darker greenish and blue-gray colored pure clay; upper most 1½ ft are a silty resistant bed	418-409
Siltstone, similar to underlying zone but of darker color and finer grain; joint planes contain calcareous and siliceous impregnation that surrounds globular masses of the siltstone	409-390
Siltstone, slightly sandy, brown; upper 10 ft is rendered resistant by siliceous impregnation; base not exposed	390-378

Drillers' Logs of Wells Through the Ringold Formation

The logs of four wells give some record of the extension of the Ringold formation below river level, as it is penetrated in wells along the Columbia

River near the type locality (fig. 1). The logs are well-drillers' records with stratigraphic designations by the writer.

1. M. C. Waters. Located in SW¼SE¼ sec. 24, T. 9 N., R. 28 E., northeast of the Richland "Wye" at an altitude of about 340 ft

Materials	Thickness (feet)	Depth (feet)
Alluvium, glaciofluviatile(?) deposits and Ringold(?) formation:		
Gravel and sand, gravel and clay	50	50
Ringold formation:		
Clay, blue	72	122
Columbia River basalt:		
Basalt, water-bearing	1	123

2. U. S. Government. Former irrigation well near old Ringold School. Located in SW¼SW¼ sec. 24, T. 12 N., R. 28 E., at an altitude of about 396 ft

Alluvium:		
Sand	12	12
Ringold formation:		
Gravel, cemented	73	85
Clay	20	105
Clay and gravel	22	127
Gravel	28	155
Boulders and gravel	6	161
Clay, blue and black	35	196
Sand	9	205
Columbia River basalt:		
Rock, black	29	234
Rock, black, and shale	6	240
Shale	17	257
Basalt, dark	214	471
Clay, gravel, and shale	25	496
Basalt	43	539
Shale	25	564
Basalt	128	692
Shale and sandstone	28	720
Basalt	35	755

3. U. S. Government. Located in SE¼NW¼ sec. 28, T. 12 N., R. 29 E., at an altitude of about 914 ft

Materials	Thickness (feet)	Depth (feet)
Eolian deposits and glaciofluviatile erratic material:		
Soil, sand, gravel, and boulders	5	5
Glaciofluviatile erratic material and caliche-impregnated Ringold formation:		
Gravel and boulders	9	14
Ringold formation:		
"Sandrock"	76	90
Clay	60	150
Sand, reddish	6	156
"Sandrock"	44	200
Clay	50	250
Sand, gray	10	260

Clay	60	320
"Sandrock"	22	342
Clay	18	360
"Sandrock," blue	40	400
Gravel	5	405
Clay	45	450
Columbia River basalt:		
Basalt, black and brown colored, porous 546-548 ft	140	590
Basalt, brown, "burnt"	11	601
Basalt, broken	31	632
Basalt, black	65	697

4. U. S. Government (at former Foster Ranch). Located in SW¼SW¼ sec. 13, T. 13, N., R. 27 E., at an altitude of about 410 ft

Materials	Thickness (feet)	Depth (feet)
Soil, silt, clay, sand	4	4
Landslide (largely materials of the Ringold):		
Silt, sandy, with clay	22	26
Sand and silt	22	48
Claystone, silty, tan	15	63
Ringold formation:		
Claystone, silty and sandy, tan	57	120
Sand with silt and clay	25	145
Silt with sand and some pebble gravel	5	150
Sand, medium and fine-grained, with silt	45	195
Silt, sandy, quartzose	10	205
Siltstone and claystone, dark, with concretions	10	215
Sand, medium to fine, gray, quartzose	18	233
Siltstone and claystone, brown, quartzose, with concretions and a few pebbles	72	305
Sand, coarse and medium, quartzose	5	310
Sand and gravel, quartz sand with basaltic pebbles	5	315
Columbia River basalt:		
Basalt, gray, weathered	4	319
Shale, black, tuffaceous	5	324
Basalt and tuff interlayered	283	607

LITHOLOGIC ASPECTS OF THE FORMATION

Distinctive Lithologic Units of the Ringold Formation

The lowest part of the extended Ringold formation commonly has been logged by well drillers as blue clays, and that name has come into use locally for the blue and green-colored silts and clayey silts that form the lowest 100 to 300 feet of the Ringold formation as herein extended. In most places they extend upward from the basalt bedrock to an altitude of about 290 feet. Drill cuttings reveal the material to be largely silt and to contain considerable sand, presumably as thin interbeds. Some beds of gravel and sand are interbedded within the blue clays and in some places even predominate over the "clays." Apparently the most distinctive feature is the blue or green color, which suggests that the material (at least at some places) has not undergone

oxidation as have the other clays and silts which lie mostly above the regional water table. The zone of the blue clays is well known to drillers, especially in the Richland area and downstream to Kennewick and Pasco, where it occupies much of the saturated zone and, in places, precludes development of ground water from the Ringold.

Above the blue clays in the southern part of the type locality, the conglomerate member extends from a variable altitude of about 290 feet upward for about 165 feet. It is the most distinctive and the most permeable part of the Ringold formation. It occurs in a linear strip, which averages 10 miles wide and about 50 miles long, between Sentinel Gap and Wallula Gap. The northeast margin of the conglomerate member runs southeast about through Wahluke and the old Ringold School, thence southeast toward Pasco. The base of the conglomerate is little, if any, higher near the north end of the White Bluffs than it is at the south end. Toward its northeastern margin the conglomerate member becomes progressively more sandy until it is made up predominantly of sand in the bluff exposures in sec. 36, T. 12 N., R. 28 E., about 5 miles north of the old Ringold School. From that locality the sand phases continues for several miles farther north. Merriam and Buwalda (1917, p. 261) described a section of 503 feet of the formation in the area of this marginal sandy phase of the conglomerate member. Outside the area of the conglomerate train, in the northernmost part of the type locality of the Ringold, the section between altitudes of 290 and 455 feet is occupied by finer grained deposits (see geologic sections C and D) such as occur above and below the conglomerate in the southern part of the White Bluffs.

The type conglomerate is a rather uniform aggregation of well-rounded pebbles and cobbles and some small boulders; the spaces between the pebbles and cobbles are almost completely filled by a matrix of medium to fine subrounded and angular siliceous sand. The pebbles and cobbles are about 65 percent quartzite and other metamorphic, granitic, and porphyritic volcanic rocks of upriver, or exotic, types and 35 percent basaltic rocks similar to the Columbia River basalt. The sand is largely all upriver quartzose material. Sand lenses and beds are common in the conglomerate; lenses of sandy silt are rare.

The position of the conglomerate member, lying in the 290-455-foot altitude zone, caused it to be exposed over a large part of the surface produced by the Columbia River's erosion of the Ringold formation. Thus, beneath much of the lowland strath of the Richland-Pasco-Kennewick area the gravelly glaciofluviatile and fluviatile deposits lie directly upon an erosional surface cut in the conglomerate member of the Ringold formation. In many wells this circumstance makes difficult the location of the actual point of contact between the two gravelly units.

The position, shape, thickness, and lithology of the conglomerate member indicate that it represents a river-laid train of gravel deposited across a basin in which quiet-water sediments had been deposited previously and were to be deposited later. Thus, it testifies to a time in which the impounding rim was still low enough to allow integration of an active river current across the basin of deposition.

The upper 500 feet or so of the Ringold formation, upward from the conglomerate member to the caliche cap, is not a marked lithologic type. It consists of intergraded layers of fine sand, silt, and clay, some zones of which attain considerable thickness. Some of the massive claystones and siltstones of this unit attain thicknesses of 20 to 40 feet in the northern part of the bluffs and are prominent cliff-forming units which can be followed for miles.

In most of the beds of the finer materials, particle sizes grade progressively toward the type of material next above and below. Thus, the successions of silt, fine sand, clay, and volcanic ash exhibit some rhythmic changes in a vertical direction, as though they resulted from deposition by the gradually shifting of currents in a large lake. However, certain grain sizes seem to dominate in the formation. In places, one particular grain size seems to be generally predominant for a considerable distance vertically and laterally, even though material of that grain size interfingers with beds of other grain sizes. Thick sand beds are most common in the southern half of the White Bluffs, massive siltstones predominate farther north, and thick claystones are most common at the extreme northern end of the bluffs.

General Lithology of the Ringold Formation

Some characteristics of the materials are summarized as follows:

Depositional:	
Rock types	Exotic, or upstream, materials predominate, almost exclusively in particles below medium sand size
Grain sizes	Silt and fine sand predominate, many thick and continuous silt and clay strata being present. One large train of cobble and pebble gravel was deposited, with interstitial sand of fine and medium grain sizes
Sorting	Well sorted, in thin beds mostly gradational to each other horizontally and vertically
Shapes of grains	Gravel is well rounded; grains of silt and fine sand are angular
Alteration:	
Rinds	Alteration rinds 1/32 to 1/8 inch thick on basalt pebbles and cobbles of the conglomerate
Induration	Silts and clays compact; gravels and sands compact and contain cemented layers; fairly resistant to wind erosion
Cementation	Generally lacking or weak, but there are strongly cemented thin layers in the conglomerate, concretions in clays, and some strongly cemented sandstone "ribs" in the sand beds
Secondary products	Secondary gypsum; fossil bone, largely petrified; calcified and silicified "caliche" cap on pre-Wisconsin surface

Cessation of Deposition of the Ringold

Apparently, deposition of the fine-grained materials that make up the uppermost part of the Ringold formation came to a rather abrupt end. That conclusion is suggested by the fact that the final depositional surface is preserved almost undissected in large areas and has been destroyed only in the rather narrow strath in which the Ringold is still being removed by the

Columbia River. The postdepositional erosive currents did not swing widely over the top of the Ringold deposits. This observation is based on the absence of current-transported deposits of late Ringold age over broad plateau areas that now represent the top of the Ringold formation. Either a tectonic or an erosional lowering of the bedrock rim occurred, or there was a change in the erosional capacity of the river. This rather sudden change caused the river to entrench itself quickly in the soft materials and to become fixed in a wide gorge cut in the Ringold formation. It has since remained in this gorge except for the aberrant diversions of the later glacial waters. Melt waters of the Wisconsin glacial stage eroded two main channels across the plateau underlain by the Ringold formation and scattered glaciofluviatile deposits and erratics rather widely to a maximum altitude of about 1,150 feet.

That the climate was dry, at least periodically, is indicated by the strong calcium and silica caliche that developed during the interval between the end of Ringold deposition and the deposition of the glaciofluviatile materials.

RELATIONS OF THE RINGOLD FORMATION TO THE STRUCTURAL DEFORMATION OF THE BASALT BEDROCK

In the White Bluffs the Ringold formation is not tectonically deformed. Many of its marker beds can be traced for miles with negligible variations in altitude. The major bedding planes of the type section are generally less than 1° from the horizontal, though dips as great as 2° can be found at the tapering ends of some beds and layers. Merriam and Buwalda (1917, p. 261) found that the strata in the White Bluffs lie parallel to the water surface of the Columbia River and stated that all recognized deformation seemed to be due to landslides.

The fine-grained materials of the basal 300 feet of the formation as extended in this paper attest to an initial lake-type impoundment during which the basin was filled to, or slightly above, what is now the 290-foot altitude and what was then the level of the overflow rim. The 160-foot-thick conglomerate indicates the re-integrated river deposited it in a trainlike strip across the basin during either a slow subsidence of at least part of the basin, or a slow elevation of the controlling rim. Finer grained materials doubtless were deposited under flood-plain conditions on the flanks of the gravel train. The inclusion of some blocks of siltstone of the Ringold in the upper part of the conglomerate indicates that the preconglomerate (or perhaps contemporary) siltstone was in places sufficiently high to be undercut and eroded along the flanks of the current-laid gravel train.

The upper 510 feet of the type section shows that fine-grained sediments again accumulated after the controlling rim had been reestablished so as to impound a lake again. The continuation of lake-type deposition to the top of the type section indicates the lake probably had not been completely filled with sediment when the controlling rim was breached, the lake was drained, and entrenchment of the river in the Ringold deposits began. The cessation of Ringold deposition was relatively sudden. It was followed by a dry climate in which the caliche cap developed on the undissected parts of the deposit. The

caliche cap existed for some time before the reinvigorated dissection and subsequent deposition of the Wisconsin stage of the Pleistocene.

One inference resulting from the available information is that the rim of the basin, the Horse Heaven Ridge, was uplifted in two stages in middle to late Pleistocene. Another is that strata of the Ringold now below river level at the type locality—the blue clays and the lower part of the conglomerate member—should have been deformed in places near the lines of displacement which cut the basalt bedrock along the Horse Heaven uplift and also along the other edges of the Pasco Basin, if the deformation at those places coincided with that in the Horse Heaven uplift. An appropriate degree of deformation is commonly reported for relatively thin layers of the Ringold at such places as the Potholes (O'Sullivan) dam site (Jones, 1946) 24 miles north of the White Bluffs, at the Roberts Ranch in the Dry Creek valley 26 miles west of the White Bluffs, and in ravines 4 miles south of the Richland Wye. As a result of regional tilting and uplift, thin layers of the Ringold formation may be present at such high altitudes as 1,400 feet at McChasney Springs on Michigan Prairie (Lupher and Warren, 1942, p. 879), and 1,200 feet in the Paradise Flats southeast of Othello. The literature contains no description of deposits of an age and lithologic type comparable to those of the Ringold formation in the area south of Wallula Gap and the axis of the Horse Heaven Ridge.

This interpretation—that the earlier Ringold deposition preceded the main uplift of the Horse Heaven Ridge and, possibly, that of other ridges and slopes farther north, and that the later (postconglomerate) deposition followed the uplift—is believed to clarify many aspects of the occurrence and deformation of the Ringold formation observed beyond the type locality by previous workers (Culver, 1937, p. 60; Jones, 1945).

The reconstructed surface of the original basalt rim at Wallula Gap in the Horse Heaven Ridge is now at an altitude of about 1,400 feet. The rim of the next younger gorge through the gap is now at an altitude of about 1,000 feet, roughly the same as that of the undissected surface on the Ringold northeast of the White Bluffs. The rock bench at 1,000 feet altitude probably represents the outlet rim of the basin at the time deposition ceased. The conclusion (with which the present writer agrees in general) that the uplift of the Horse Heaven Ridge at Wallula Gap occurred just prior to and contemporaneously with the deposition of the Ringold formation, was proposed by Warren (1941). It disagrees with Waters' map (1955) and the statement on page 680 of his paper that the Horse Heaven Ridge has been in existence and the Wallula Gap has been used by the Columbia River since late Ellensburg (Pliocene) time.

SUMMARY AND CONCLUSIONS

1. In addition to strata in the type section, the Ringold formation can be extended downward to include similar strata below the level of the Columbia River at the White Bluffs.

2. The materials of the Ringold formation in the type locality are largely derived from upriver sources. The grains below medium sand sizes, with the

exception of small amounts of volcanic ash, are almost entirely from upriver sources.

3. The average section at the White Bluffs includes a blue clays unit of silt, clay, sand, and gravel which extends upward from the basalt bedrock at about sea level to an altitude of about 290 feet, a 160-foot thickness of weakly cohesive gravel and sand called the conglomerate member of the Ringold formation, and an upper unit of silt, sand, clay, volcanic ash, and gravel which lies in the general altitude range of 450 to 960 feet. A 15-foot-thick layer of "caliche" caps the section. It originated prior to the Wisconsin glacial stage.

4. The Ringold strata in the type locality are essentially horizontal but depositional conditions imposed local dips as great as 2 degrees. The strata above the conglomerate member have features that indicate deposition by shifting currents in a lake. The conglomerate member was deposited by river currents.

5. The strata of the Ringold formation indicate a history which includes, successively, (a) impoundment of the Columbia River during the deposition of the blue clays, (b) integration of the course of the Columbia River across the basin and the deposition of a 160-foot-thick gravel and sand train, the conglomerate member, (c) reimpoundment of the river, during which time the upper 510 feet of the deposits of the type section were laid down by shifting currents, as an incomplete fill of a lake basin, (d) drainage of the lake and rapid entrenchment of the river into the Ringold formation after breaching of the bedrock rim at Wallula Gap, and (e) development of a caliche cap layer on the Ringold prior to the arrival of the glaciofluviatile and fluviatile deposits at the time of the Wisconsin glacial stage farther upriver.

6. The controlling agent in the two-stage impoundment of the Columbia River during Ringold time was the uplift of the Horse Heaven Ridge. As the depositions of the Ringold formation and the uplift were contemporaneous, the age of the main uplifts of the Horse Heaven Ridge is interpreted as middle to late Pleistocene.

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